

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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REPLY TO
ATTN OF: GP

October 15, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned
U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,238,715

Corporate Source : Lewis Research Center

Supplementary
Corporate Source : _____

NASA Patent Case No.: XLE-01124

GParker

Gayle Parker

Enclosure:
Copy of Patent

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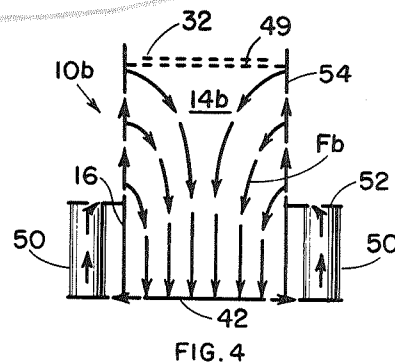
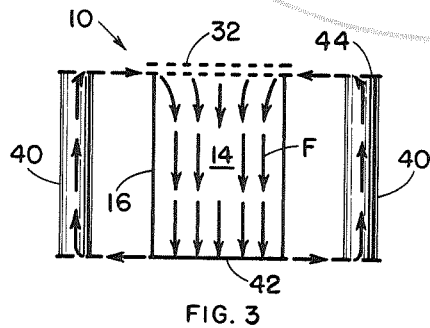
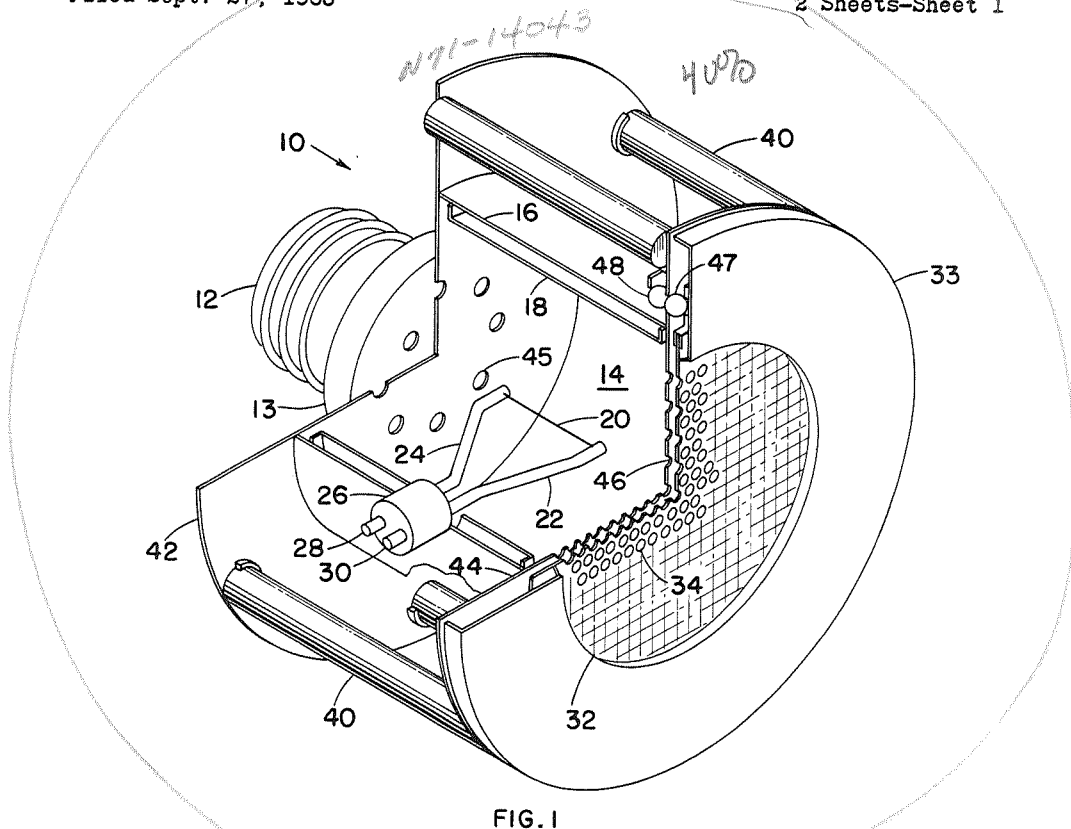
P. D. READER ET AL

3,238,715

ELECTROSTATIC ION ENGINE HAVING A PERMANENT MAGNETIC CIRCU.

Filed Sept. 27, 1963

2 Sheets-Sheet 1



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3,238,715

ELECTROSTATIC ION ENGINE HAVING A PERMANENT MAGNETIC CIRCUIT

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2 Sheets-Sheet 2

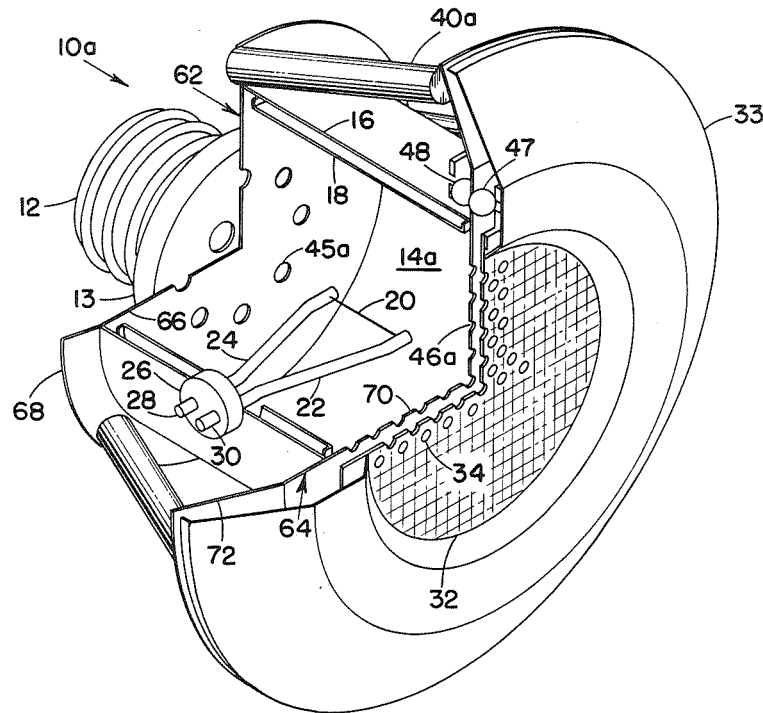


FIG. 2

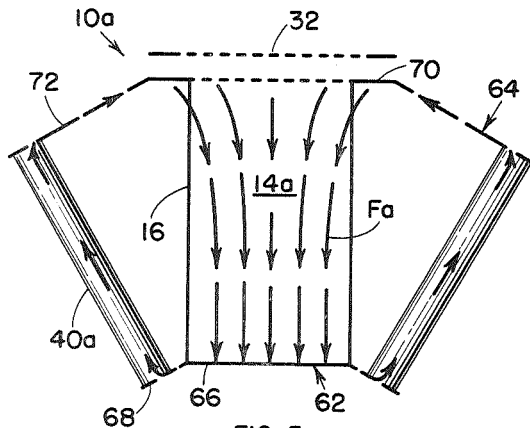


FIG. 5

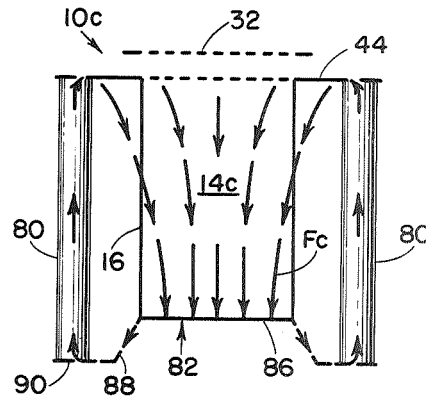


FIG. 6

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ELECTROSTATIC ION ENGINE HAVING A PERMANENT MAGNETIC CIRCUIT

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10 Claims. (Cl. 60—35.5)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention is concerned with electrostatic engines and, more particularly, with an electron bombardment ion engine having an improved structure for providing a magnetic field that has the shape and strength required for optimum efficiency of operation of the discharge.

Electron bombardment ion engines of the type shown in copending application Ser. No. 139,007, now Patent No. 3,156,090, utilize wrappings of high conductivity wire about their ion chambers to produce the required magnetic field as current is passed through the wire. This wire coil or electromagnet requires an electrical power supply which adds weight to the system, and to obtain a high electrical efficiency a heavy coil is needed. The reduction of the overall weight of the engine system is an important consideration in designing electrostatic engines.

These disadvantages have been overcome by the present invention wherein a permanent magnet circuit is provided by a group of permanent magnets arranged with permeable paths to conduct and properly distribute the magnetic lines of flux through the ion chamber. The permeable paths are incorporated in the engine as structural members, and because many of these members are normally required in an engine utilizing an electromagnet the overall weight of the present engine is approximately equal to that of an engine with an electromagnet.

The electrical power supply required by the electromagnet is eliminated by the present structure thereby reducing the total weight of the system. The required magnetic field is produced by apparatus which is passive because after the magnets have been initially magnetized and placed in the circuit no further activation, control, or power supply is required for proper operation.

It is, therefore, an object of the present invention to produce an improved electron bombardment ion engine having a permanent magnetic circuit which is reliable, mechanically strong, and efficient with a reduced total system weight because of the omission of the weight of the power supply required by an electromagnet.

Another object of the invention is to provide an improved electron bombardment ion engine utilizing permanent magnets which serve as a return path for the magnetic flux of the engine thereby enabling engine modules in a multi-engine array to be positioned closer together without magnetic field interaction whereby the total engine area is reduced by the elimination of dead space which produces higher thrust per unit area.

Other objects and advantages of the invention will be apparent from the specification which follows and from the drawings wherein like numerals are used throughout to identify like parts.

In the drawings:

FIG. 1 is an axial quarter section of an electron bombardment ion engine shown in perspective utilizing an improved magnetic circuit constructed in accordance with the invention;

FIG. 2 is an axial quarter section of an electron bom-

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bardment ion engine shown in perspective utilizing an alternate embodiment of a magnetic circuit constructed in accordance with the invention;

FIG. 3 is a schematic view illustrating the magnetic circuit of the electron bombardment ion engine shown in FIG. 1;

FIG. 4 is a schematic view of an electron bombardment ion engine having a modified magnetic circuit;

FIG. 5 is a schematic view of the magnetic circuit of the electron bombardment ion engine shown in FIG. 2; and

FIG. 6 is a schematic view of an alternate embodiment of a magnetic circuit for an electron bombardment ion engine.

Referring now to the drawings, there is shown several electrostatic ion engines which utilize electron-bombardment ion sources. In each of these engines, neutral particles in the form of a gaseous propellant enter the upstream end of an ion chamber in which high-velocity electrons thermionically emitted by a cathode in the form of a hot filament in this chamber ionize these particles to form a plasma. A screen grid and accelerator grid at the downstream end of the ion chamber focus and accelerate ions that reach that end. The thrust producing mechanism of this device is the momentum change of the ions as they are accelerated by the electrostatic field which is applied between the screen and accelerator grids.

Both FIGS. 1 and 2 show electron bombardment ion engines 10 and 10a having a propellant supply comprising a source 12 in the form of a cylindrical container or boiler which furnishes the propellant, such as mercury vapor, to a manifold 13. An ion chamber 14 within a tubular casing 16 is in communication with the manifold 13 in a manner which will be described later in detail. A tubular anode 18 is concentrically supported within the casing 16 and insulated therefrom. A cathode 20, such as a tungsten filament, is centrally supported in the center of the chamber 14 by a pair of arms 22 and 24 carried by an insulator 26 mounted on the casing 16. A pair of electrical leads 28 and 30 extending from the outwardly directed surface of the insulator 26 are in electrical communication with the cathode 20 through the arms 22 and 24.

A grid 32 in the form of a plate having a plurality of apertures 34 is positioned at the downstream or exhaust end of the chamber 14 to accelerate the ions in the plasma that move to this end of the engine. The grid 32 is secured to and in electrical contact with an annulus plate 33. Both the anode 18 and the cathode 20 as well as the accelerator grid 32 and its annulus plate 33 are connected to suitable sources of power in the manner shown in the aforementioned copending application Ser. No. 139,007, now Patent No. 3,156,090, and the propellant is ionized in the chamber 14 in the manner described in this copending application.

The particle densities of the plasma in the chamber 14 are sufficiently small that the mean free path for ionization is quite long thereby necessitating the containment of the high velocity ionizing electrons within the ion chamber 14. A magnetic field is utilized to lengthen the path of these high-velocity electrons that are emitted from the cathode 20. According to the present invention, such a magnetic field is provided by a group of permanent magnets arranged with permeable paths to conduct and properly distribute magnetic lines of flux.

Referring to the embodiment of the invention shown in FIG. 1 and illustrated schematically in FIG. 3, a plurality of permanent magnets 40 in the form of elongated cylinders are arranged concentrically about the periphery of the casing 16 with the normal axis of each of the cylinders being substantially parallel with the axis of the casing

16. The magnets 40 are equally spaced and supported by a pair of spaced plates 42 and 44 of a magnetic permeable material, such as soft iron, which form not only structural components of the ion engine 10 but also pole pieces which provide permeable paths for magnetic lines of flux F as illustrated in FIG. 3. Both the upstream plate 42 and the downstream plate 44 are substantially planar and normal to the longitudinal axis of the engine 10, and the central portion of each plate forms an end wall of the ion chamber 14. The upstream plate 42 contains a plurality of apertures 45 which serve to distribute the flow of the gaseous propellant from the manifold 13 into the ion chamber 14. The downstream plate 44 contains a plurality of apertures 46 in substantial alignment with the apertures 34 in the grid 32 to reduce the impingement of the ions on the accelerator grid 32 thereby reducing erosion. Both the plates 42 and 44 are in electrical contact with the casing 16 while the accelerator grid 32 and annulus plate 33 are insulated from and maintained in a fixed spaced relationship relative to the plate 44 by insulators 47 and 48. The plates 42 and 44 as well as the casing 43 are connected to a suitable power source in a manner described in copending application Ser. No. 139,007, now Patent No. 3,156,090, and are operated at the same potential.

Referring to FIG. 4, there is shown an electron bombardment ion engine 10b having an accelerator grid 32 and a screen grid 49 mounted at the downstream end of an ion chamber 14b within a casing 16 in the manner described in the aforementioned application Ser. No. 139,007, now Patent No. 3,156,090. In this embodiment, a plurality of permanent magnets 50 in the form of cylinders each having a shorter length than that of the ion chamber 14b are arranged concentrically about the casing 16. The upstream plate 42 or pole piece is substantially planar as in the case of the embodiment shown in FIG. 1, and a marginal peripheral portion of this plate engages the upstream end of each of the magnets 50. An opposite pole piece is formed by a radially extending annulus 52 which engages the downstream ends of the magnets 50 and a sleeve 54 which engages a portion of the casing 16 between the annulus 52 and exhaust end of the chamber 14b. It is contemplated that the sleeve 54 may be eliminated by making this downstream portion of the casing 16 of a magnetically permeable material while the upstream portion between the annulus 52 and the plate 42 is of another material that is not magnetically permeable. As illustrated by the flux lines Fb in FIG. 4 this structural arrangement produces a tapered magnetic field having flux lines which diverge or become less dense from the upstream end towards the downstream end for improved efficiency.

In the embodiment shown in FIG. 2 and illustrated schematically in FIG. 5, a plurality of permanent magnets 40a in the form of elongated cylinders are mounted circumferentially around the casing 16 as in the previous embodiments, but the normal axis of each cylinder is angularly disposed to the axis of the ion engine 10a. The permanent magnets 40a are equally spaced about the casing 16 and are mounted by spaced plates 62 and 64 which likewise function as both structural elements and permeable paths for the magnetic lines of flux illustrated by the arrows Fa in FIG. 5. The upstream plate has a centrally disposed planar portion 66 which contacts the upstream end of the casing 16 and forms an end wall of the ion chamber 14a. A plurality of apertures 45a in the central portion 66 communicates with the interior of the propellant manifold 13. The upstream plate 62 further includes an angularly extending flange 68 around the central portion 66 which mounts the upstream end of each of the permanent magnets 40a.

The downstream plate 64 likewise includes a central portion 70 containing a plurality of apertures 46a which are in substantial alignment with the apertures 34 to reduce erosion of the accelerator grid 32. An angular flange

72 extends around the periphery of the central portion 70 and engages the downstream ends of the magnets 40a. Insulators 47 and 48 are utilized to mount the annulus plate 33 and accelerator grid 32 on the plate 64 as previously described. The magnetic field illustrated by the flux lines Fa in FIG. 5 has a tapered configuration.

Another ion engine 10c having a permanent magnetic field with a tapered configuration is illustrated in FIG. 6. In this embodiment, a plurality of permanent magnets 80 having a length that is longer than the ion chamber 14c are mounted in spaced relationship about the casing 16. These magnets 80 are mounted between an upstream plate 82 and a downstream plate 44 which is substantially identical with the corresponding plate of the embodiment shown in FIGS. 1 and 3. The upstream plate 82 includes a central portion 86 which forms the upstream end wall of the ion chamber 14c and has a plurality of apertures in communication with the propellant manifold as in the case of the previous embodiments. A circumferential flange 88 encircles the central portion 86 and extends angularly upstream away from the ion chamber 14c. A radially extending annulus 90 encircles the upstream end of the flange 88 and engages the upstream end of each of the magnets 80. The configuration of the plate 82 distributes the magnetic lines of flux Fc to form the tapered configuration shown in FIG. 6.

While several embodiments of the present invention have been illustrated and described, various structural modifications may be made to these embodiments without departing from the spirit of the invention or the scope of the subjoined claims. By way of example, the various permanent magnets have been described as being elongated cylinders. It is contemplated that permanent magnets having other shapes and configurations may be utilized. For example, the magnets may be shorter than those illustrated with the remaining length being supplied by outwardly extending pole pieces which contact the spaced mounting plates. Also, a single permanent magnet which encircles the casing may be used.

What is claimed is:

1. An electrostatic ion engine comprising

a casing forming the peripheral wall of a chamber for containing an ionizable propellant,

a source of said propellant positioned at one end of said casing,

a thermionic emitting cathode within said casing for bombarding said propellant with high velocity electrons to form ions,

an apertured grid having a relatively high negative potential relative to said cathode positioned at the opposite end of said casing remote from said propellant supply to accelerate said ions away from said engine,

a plurality of permanent magnets positioned around said casing to form a magnetic field about said propellant and said cathode whereby the paths of said high velocity electrons are lengthened to increase the rate of collision of said electrons with particles of said propellant,

a pair of spaced members for mounting said magnets, said members being of a magnetic permeable material and in contact with said casing to form the end walls of said chamber, and means for maintaining said members and said casing at the same electrical potential.

2. An electrostatic ion engine as claimed in claim 1 wherein one of said members is positioned between said one end of said casing and said propellant source, said member having a plurality of openings therein for conveying said propellant from said source to said chamber and distributing the same therein.

3. An electrostatic ion engine as claimed in claim 1 wherein one of said members is positioned between said opposite end of said casing and said grid, said member having a plurality of apertures therein in substantial align-

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ment with the apertures in said grid for shielding the same from said ions to reduce erosion.

4. An electrostatic ion engine as claimed in claim 1 wherein said casing is tubular and said magnets are cylindrical and equally spaced about said casing.

5. An electrostatic ion engine as claimed in claim 4 wherein the normal axis of each of said magnets is substantially parallel to the axis of said casing.

6. An electrostatic ion engine as claimed in claim 4 wherein the normal axis of each of said magnets is angularly disposed to the axis of said casing.

7. An electrostatic ion engine as claimed in claim 4 wherein each of said magnets and said casing are substantially equal in length.

8. An electrostatic ion engine as claimed in claim 4 wherein each of said magnets has a length substantially longer than said casing and one of said members includes a circumferential flange extending angularly outward from said casing, and
a radially extending annulus adjacent said flange in engagement with an end of each of said magnets.

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9. An electrostatic ion engine as claimed in claim 4 wherein each of said magnets has a length substantially shorter than said casing, and one of said members comprises a flange extending radially outward from said casing.

10. An electrostatic ion engine as claimed in claim 9 including

a sleeve mounted concentric with said casing and in engagement with said flange.

References Cited by the Examiner

UNITED STATES PATENTS

| | | | |
|------------|---------|-----------------|---------|
| Re. 25,440 | 9/1963 | Engelman | 313—157 |
| 2,681,421 | 6/1954 | Gethmann | 313—84 |
| 2,919,370 | 12/1959 | Giannini et al. | |
| 2,997,013 | 8/1961 | Rice | 60—35.5 |
| 3,156,090 | 11/1964 | Kaufman | 60—35.5 |

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